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WSTIAC

Weapon Systems Technology Information Analysis Center

The Continuing War Against IEDs

The WSTIAC 10: IED Defeat

Stealthy Antennas

WSTIAC Quarterly
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This issue of the WSTIAC Quarterly features articles on The Continuing War Against IEDs, WSTIAC 10 Spotlight: IED Defeat, and Stealthy Antennas. Included the WSTIAC Calendar of Events and the Directors Corner. Details on several Training Courses sponsored by WSTIAC are also included in this issue.

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Director's Corner

Welcome to the latest edition of the *WSTIAC Quarterly*. The WSTIAC program has continued its strong start in Fiscal Year 2008. As we approach the final quarter of this fiscal year, I can say that WSTIAC is continuing to collect and disseminate information and provide technical expertise on weapons systems technologies at a rate that is significantly greater than this time last year. This means supporting a greater number of web inquiries, adding more scientific and technical documents to our weapons systems technology library, and continuing to host students in our world class weapon systems technology training courses. In terms of providing technical solutions and expertise, we are at a contract effort pace that is expected to exceed previous WSTIAC levels.

As a gauge of our ongoing efforts to improve, I strongly recommend that you visit our WSTIAC website at http://wstiac.alionscience.com. In addition to the wealth of knowledge and capabilities that are provided to support you, we have implemented distinct customer sections (i.e. warfighters, project managers, and engineers/scientists) to better focus on your needs. Also, the "WSTIAC 10" on the website will provide you with a clear understanding of those weapons related strategic areas that WSTIAC is focusing on.

On a side note, I want to emphasize that all government agencies can take advantage of the information and technical expertise that WSTIAC offers. On the technical expertise side, through the WSTIAC contract we can assist you with resolving those technical issues or challenges that require additional capabilities. With this in mind, let me emphasize a few critical points about using our contract:

- The scope must be weapon system related
- The effort must involve some aspect of research and development
- It must focus on products, not manpower; completion versus term
- It must rely on technical experts' input
- It can not be advisory and assistance services or service support related

If you have any questions or would like to find out more about utilizing WSTIAC's resources and capabilities, please feel free to contact us: http://wstiac.alionscience.com/contact

For this edition of the *WSTIAC Quarterly*, I believe that you will find the feature article about the Joint Improvised Explosive Device Defeat Organization (JIEDDO) very interesting. Certainly, it is evident that improvised explosive devices (IEDs) are a persistent threat to American efforts in Iraq and Afghanistan. In terms of WSTIAC, it is one of the ten areas on which we are focusing our efforts in terms of gathering additional information and providing technical expertise. This includes a new IED training class that we are developing. The course will provide warfighters and engineers an understanding of the history, technology, engineering principles, tactics, and countermeasures systems that we are employing. We expect the course to be completed by early fall of this year.

The second article in this issue provides a technically oriented introduction to the world of stealthy antennas. The article features an overview of some of the basic principles that guide the design of these components which must maintain a minimal radar cross section. I hope that you find these articles and the rest of the publication useful in contributing to your efforts to support our warfighters.

Mark Rider
WSTIAC Director

About the cover:
Background: A roadside bomb explodes and bursts into a fireball simulating an IED that soldiers might face in Iraq. This is but one of the many tools used to provide realistic training for units that come to the National Training Center (NTC) to enhance and improve their war fighting skills for future deployments. (Photo by Master Sgt. Johancharles Van Boers and provided courtesy of the US Army.) Foreground: Soldiers track down and collect ordnance to prevent them from being used as IEDs. (Photos provided courtesy of JIEDDO.)

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The Continuing War Against Improvised Explosive Devices

An Overview of the Joint IED Defeat Organization

Irene Smith
Michael Coderre
Joint IED Defeat Organization
Pentagon, Washington DC

It's the weapon that won't go away. Cheap, lethal and low-tech, improvised explosive devices (IEDs) are a persistent strategic threat to American efforts in Iraq and Afghanistan (Figure 1). Buried alongside roads, packed into houses and hidden throughout neighborhoods, they are the leading source of US casualties in both theaters.

Appreciating the scope and nature of the threat, the Pentagon consolidated its counter-IED (C-IED) focus in February 2006 with the establishment of the Joint IED Defeat Organization (JIEDDO). Leading all Department of Defense IED defeat efforts in direct support of the warfighter, JIEDDO works to find, develop, test and rapidly deliver emerging counter-IED capabilities to theater and to training venues worldwide.

Army Lt. Gen. Thomas F. Metz, Director of JIEDDO, is no stranger to the IED fight. Having served as the first Multi-National Corps commander in Iraq from 2004 to 2005, Metz was selected by the Pentagon to lead the organization. "It's a very, very complex problem," Metz says straightforwardly. "Man has been ambushing man for a long time."

Since taking over in January 2008, Metz visited Iraq and Afghanistan for a first-hand perspective of current counter-IED operations. He made his second visit as JIEDDO's director in May. Metz's survey of JIEDDO's efforts also included the nation's Combat Training Centers, where the organization works in support of the Services to bring Soldiers, Sailors, Airmen and Marines up-to-speed on the latest, most refined and realistic counter-IED training available. "We are seeing success against the IED. Overall attacks are down, as is the lethality," Metz explained. Metz attributed the drop in IED attacks in Iraq to a variety of factors: the troop surge, the introduction of mine-resistant, ambush protected (MRAP, see Figure 2) vehicles and a number of successful C-IED initiatives. "My first three months at JIEDDO have given me the opportunity to be current on the IED fight in-theater and to see how our service members are being trained in counter-IED operations," Metz said. "We have been effective; the surge has worked." Metz cautioned, saying he's far from declaring victory over IEDs. "The enemy still has capacity. This whole effort is a continued match and counter-match between a very smart, nimble, thinking enemy and a very smart, nimble, thinking coalition force."

Over the last year, JIEDDO has rapidly fielded and funded a number of initiatives that have contributed to fewer IED attacks and ensuing casualties. During that period, 17 major counter-IED initiatives took shape at JIEDDO, each worth more than $25 million. What sets JIEDDO apart from traditional acquisition sources – and allows it to quickly field its initiatives – is its use of the Joint IED Capability Approval and Acquisition Management Process (JCAAMP). An expedited acquisition process (shown in Figure 3), JCAAMP dramatically shortens, the time between recognition of a developing IED threat and the placement of a counter-IED initiative in the hands of the warfighters. JIEDDO's goal is to place C-IED initia-

Figure 1. The crater caused by a suicide-initiated, vehicle borne IED in Bayji, Iraq in December 2007.

Figure 2. Mine-Resistant, Ambush Protected Vehicle (Photo by Air Force Tech. Sgt. Jeffrey Allen and provided courtesy of US Department of Defense).

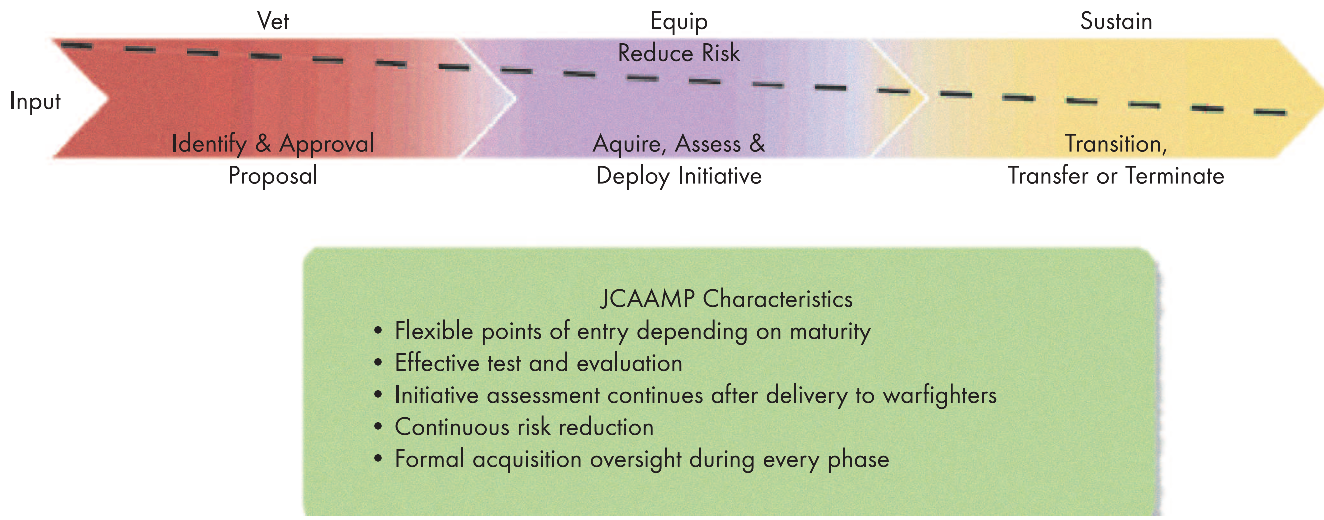

Figure 3. **JIEDDO's JCAAMP Process.**

tives into the hands of warfighters within two to eight months. "One thermal-imaging program designed to enhance detection of IEDs, for example, took only about six weeks to deploy," Metz says. Using a balance of intelligence, training and technology, JIEDDO supports the warfighter through three lines of operation: Attack the Network, Defeat the Device, and Train the Force.

ATTACK THE NETWORK

"Attack the Network is one of the biggest areas where JIEDDO has made progress," explains Metz. "I'm convinced that defeating IEDs requires attacking the devices at their source. By targeting the networks that fund and build IEDs, we can attack the enemy before they take action." To do this, JIEDDO established its Counter-IED Operations Integration Center (COIC) in 2006. The COIC combines multi-source intelligence with a robust set of analytical technologies to create a common operational and intelligence picture of worldwide IED systems. Synthesizing seemingly unrelated information and data sources, the COIC creates a detailed operational picture in support of offensive operations against IED networks. The COIC also serves as a conduit for strategic feedback and collaborative analysis.

Figure 4. **A Buffalo vehicle uses its hydraulic arm to probe a trash pile thought to contain an IED. (Photo by SSG Matthew Acosta and provided courtesy of US Army)**

Along with delivering fused intelligence packages to theater, JIEDDO works actively in theater to disrupt IED networks. After noting similarities between American organized crime and IED networks, JIEDDO created the Law Enforcement Professionals (LEP) program to use the knowledge and skill of former law enforcement experts to attack IED network activities. The LEP program provides commanders in Iraq and Afghanistan with experienced law enforcement agents from the Federal Bureaus of Investigation (FBI), the Drug Enforcement Agency (DEA), the Bureau of Alcohol, Tobacco, Firearms and Explosives (ATF), and several major metropolitan police departments to assist in identifying, monitoring, penetrating, and suppressing IED networks. Rounding out the organization's major network attack initiatives is the Human Terrain System. A comprehensive civil affairs initiative funded initially by JIEDDO and operated by the Army addresses cultural awareness at operational and tactical levels. Comprised of social scientists, military personnel and cultural experts, the human terrain teams provide knowledge to understand and influence the social, ethnographic, cultural, economic, and political elements of the indigenous populations and give commanders non-lethal options to achieve their objectives.

DEFEAT THE DEVICE

Defeat the Device works to enhance commanders' freedom of action for safe operations and to reduce the effects of IED detonation at the point of attack. These include route clearance, device neutralization, explosive detection, military explosive ordnance disposal, and vehicle and personnel protection (see Figures 4 & 5).

Figure 5. **Soldiers secure ordnance that the enemy could have otherwise used for IEDs. (Photo provided courtesy of JIEDDO)**

In 2007, JIEDDO funded over 14,000 jammers for Army and Marine Corps units bringing the total number of IED jammers purchased to over 37,000. Known collectively as the Counter Radio-Controlled Electronic Warfare (CREW) system, these vehicle-mounted, man-portable or fixed-site devices prevent radio-controlled IEDs (RCIED) from detonating. Continued fielding

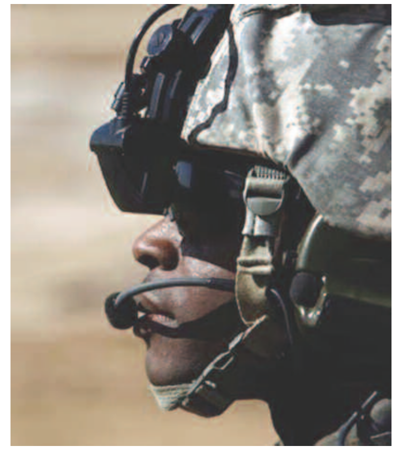

Figure 6. **(a) The Warrior UAV demo was built by General Atomics Aeronautical Systems. (b) The Land Warrior system is an integrated digital fighting system that improves situational awareness and survivability for dismounted soldiers. The system provides digital imagery and GPS location information that provides soldiers exact locations of enemies or IEDs. (Photos provided courtesy of US Army)**

and enhancements of CREW systems over the year influenced the enemy to employ other initiation methods, resulting in a 60 percent drop in radio initiator use in theater.

Robotics are also a successful tool in safely removing IEDs from the battlefield. The MARCBot/Xbot is one of JIEDDO's newer, smaller, faster and more agile devices used for IED interrogation. It gives the soldier the option of going out to inspect an IED using a small robot with a camera and a claw instead of a cumbersome blast suit. This decreases the chance of IED-related casualties and opens up the possibility for exploiting the device for biometric or forensic data.

To assist service members on the road in-theater, JIEDDO developed the Driver's Vision Enhancer Plus (DVE+) system. DVE+ is an infrared imaging device designed to give a driver a clear view of the road, even with a large armored vehicle operating under degraded visibility conditions. This year JIEDDO funded the procurement of 1,000 DVE+ devices.

While the MARCBot and DVE+ operate on the ground, JIEDDO also fields Defeat the Device initiatives in the air. Unmanned airborne systems have been highly successful in providing surveillance capability for counter-IED efforts. A successful counter-IED initiative that has been transferred to the Army within the last year is Warrior Alpha, providing intelligence, surveillance, and reconnaissance capabilities to warfighters on the ground (see Figure 6).

TRAIN THE FORCE

"Last, but certainly not least, is our training component," Metz said. "JIEDDO will spend up to $300 million this year on training to help soldiers learn how to deal with roadside bombs. We're continuing to shorten the time it takes to get counter-IED capabilities and training devices to our service members. Our most important resource is the warfighter. He needs to be fully-trained and properly equipped for counter-IED operations, which is where JIEDDO will continue to focus."

As the core training component of JIEDDO, the Joint Center of Excellence (JCOE), headquartered at Fort Irwin ensures that deploying service members have the opportunity to train with the counter-IED tactics and equipment currently found in-theater and in conditions that mirror those found in Iraq and Afghanistan. The goal of the JCOE is to support the services in providing training units a realistic experience in all facets of IED defeat, including identification of IEDs and their components, attacking the networks that bring the devices into the battlefield, and properly employing the tools available to defense against these weapons. Additionally, JIEDDO supports coalition and partner training through funding of equipment to support C-IED training at US training centers in Europe. During FY07, a total of 19 nations received IED defeat training in Europe and in theater prior to serving in US-led coalitions.

The challenge facing Metz and JIEDDO is the constantly changing electronic environment and ongoing technological advancements of cell phones. During 2006 in Iraq, the command wire IED was the preferred IED-initiation system, while in Afghanistan, radio controlled IEDs prevailed. Today's threat includes the command wire detonation, deeply-buried IEDs and suicide bombers. "Basically any piece of electronic equipment that beeps, buzzes, squawks, vibrates, whistles can be used as an IED detonator," Metz said. "All IEDs are a variation of a simple design consisting of a firing switch, blasting cap, arming switch and power source.

Cell phones (see figure 7), wireless doorbells, two-way radios, toy RC systems, wireless telephones, car locking systems and garage door openers are all commonly used as command initiative

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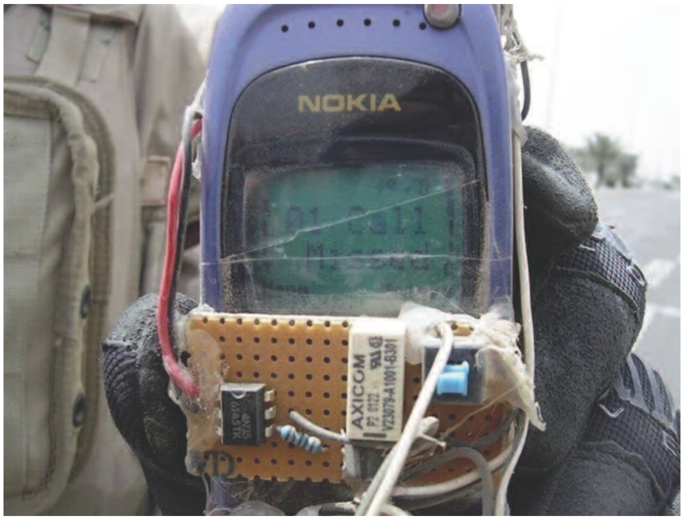

Figure 7. **Cell phones can be used to detonate radio-controlled IEDs. (Note the one missed call.) JIEDDO's Counter Radio-Controlled Electronic Warfare vehicle-mounted, man-portable and fixed-site jamming systems prevent these devices from detonating. (Photo provided courtesy of JIEDDO)**

devices in Iraq. Insurgents use cell phones as initiators to set off explosive devices. Instead of the phone ringing, it sends the power to a blasting cap."

The threat of IEDs will continue, Metz said, but he's committed to make life more difficult for those who choose to use them. "It's about pushing back and making tomorrow more risky than today for everyone in the enemy IED networks." Metz said. "What I want to happen is, if you are in the enemy IED business, every day is going to be a little more dangerous to you to be killed, captured, or making your network a more expensive thing to propagate," he said. His hope, he added, is that the tactic will drive the enemy to give up on IEDs altogether. "We will defeat the IED as an effective tool for those who are intent on harming our service members, our coalition partners and innocent civilians," Metz said. "JIEDDO will aggressively continue to develop new, innovative ways to rapidly find, develop and deliver emerging capabilities to counter IEDs and we will remove it as a strategic tool for the enemy."

For more information, please contact:
Joint IED Defeat Organization
5000 Army Pentagon
Washington, DC 20301-5000
https://www.jieddo.dod.mil
(703) 602-5064

IED Defeat

The Improvised Explosive Device (IED) has emerged as a key element of the enemy's order of battle in Iraq and Afghanistan, and in Western countries designated as targets. The intent is to maximize military and civilian casualties for propaganda effect. The goal is first to compel coalition nations to withdraw their forces from Moslem countries and then to topple the local governments and impose their own brand of Sharia Law. A straight fight with coalition forces or even reasonably well-trained and equipped local forces being out of the question, the enemy has increasingly resorted to IED attacks.

IEDs may be classified according to the base material used. In Afghanistan, they are frequently fashioned from mines left behind by retreating Soviet forces in the 1980s. In Iraq, they commonly employ ordnance (mines, artillery shells) which were stockpiled in vast quantities by the Saddam Hussein regime and which exist in caches and dumps throughout the country. In addition, materials such as plastic explosive and special triggering devices are being supplied by hostile powers such as Syria and Iran. Almost any explosive can be employed in an IED, including commercial dynamite, black powder, and ammonium nitrate. All of these have been encountered in the field.

Another way to classify IEDs is by the triggering method used. "Victim-operated" IEDs, or boobytraps, are set off by contact or pressure switches, trip-wires, photo-detectors and the like. Pressure switches, designed to be planted in a roadbed and set off by heavy military vehicles but not ordinary passenger cars, have been used extensively in Iraq. Radio-controlled IEDs use commonly available transmitter/receiver combinations, such as cell phones, walkie-talkies, automobile key fobs, etc. There is usually a triggerman, observing from a safe stand-off distance, who sets off the IED by remote control at an opportune moment. Wired control, as opposed to radio, is also used but less effectively. Suicide IEDs are set off by an attacker wearing an explosive vest or driving a car loaded with explosives.

Mastering the IED threat requires appropriate tactics and training of forces, such as avoiding predictability of movements, being alert to landscape changes indicating enemy activity, looking out for the triggerman (or the cameraman – the insurgents use video footage of successful attacks for propaganda and recruiting), and so on. Defeating the IED infrastructure requires cultivation of human intelligence and its timely exploitation. In the technical realm, efforts to counter IEDs concentrate on detection and neutralization. They include:

- Automation/robotics, examining & neutralizing a suspected device without exposing personnel to hazard
- Long-term imaging and visionics, identifying changes indicating planted IEDs
- Ongoing surveillance of key areas, including quick-reaction strike at threats (UAV/Viper Strike)
- Radio jamming of commonly-used triggering devices (e.g. Warlock)
- Chemical and spectral detection of explosives
- Optimization of ground-penetrating radar (GPR) to detect IEDs
- Up-armoring, layered/composite armor

- **IED Defeat**
- **Embedded Training Systems**
- **Lethality**
- **Target Identification & Engagement**
- **Asymmetric & Irregular Warfare**
- **Power & Energy**
- **Command & Control**
- **Weapon Systems & Munitions Readiness, & Asset Visibility**
- **Non-Lethal Weapons**
- **Capabilities, Effectiveness, & Requirements Analysis**

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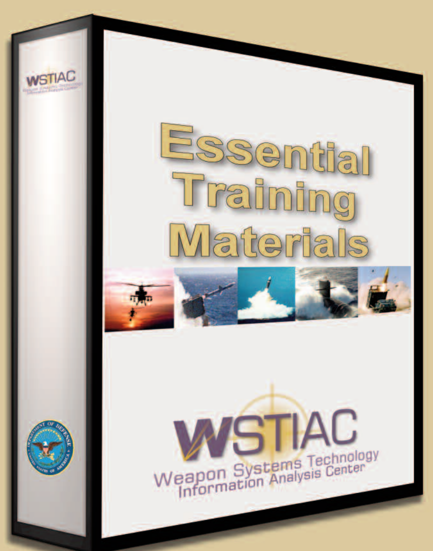

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COURSE SPOTLIGHT

IMPROVISED EXPLOSIVE DEVICE COURSE

This 2 1/2 day short course provides an introduction to the nature of the improvised explosive device (IED) threat and measures currently being employed to counter it. The course provides the historical context of IED development and use, details of IED construction, methods of deployment, and background information pertaining to munitions and explosives. Active and defensive technological and tactical countermeasures are presented, including lessons learned in the current conflicts in Iraq and Afghanistan.

Topics include:

- IED Elements and Construction
- IED Operational Deployment and Effectiveness
- Identification/Sensors
- State of the art of representative US and foreign countermeasures systems
- Personnel Protection/Armor
- Technology trends

IED detection and countermeasures systems discussed include fielded and/or developmental US and foreign systems, such as Warlock and the IED Countermeasures Equipment (ICE), Joint IED Neutralizer (JIN), Thor, and the Trophy Active Defense System.

DIRECTED ENERGY WEAPONS

Provides an introduction to the basic principles and techniques of Directed Energy Weapons (DEWs). Weapon System applications are also thoroughly analyzed. The technologies behind each type of DEW are examined and the critical path components are identified and explored with respect to their effect on future DEW development.

IMPROVISED EXPLOSIVE DEVICE (IED)

The objective of this course is to inform materiel and combat developers, systems analysts, scientists, engineers, managers and business developers about the IED threat and countermeasures.

INTRO TO SENSORS AND SEEKERS

Provides an introduction to the most commonly used sensors and seekers employed in smart munitions and weapons. It is oriented to managers, engineers and scientists who are engaged in smart weapons program development and who desire to obtain a deeper understanding of the sensors they must deal with, but who do not need to design or analyze them in depth.

SMART/PRECISION WEAPONS

This course is aimed at providing general knowledge about smart weapons technology and a source of current information on selected US programs across the military services including system description, concept of employment, performance characteristics, effectiveness and program status.

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WSTIAC Success Story...

WSTIAC SUCCESS STORY: IMPROVING COMPONENT SERVICE LIFE FOR CRITICAL AIRCRAFT COMPONENTS

WSTIAC has been contracted by the Naval Air Systems Command to provide technical and program management expertise to enhance the operational readiness and service life of critical aviation system components. WSTIAC personnel have been integral members of the Integrated In-Service Reliability Program (IISRP) Team since its inception. The IISRP Team was created in 1999 and evolved from Business Process Reengineering Initiative 3.3, to an integrated product team (IPT) comprised of members from the 4.0 and 6.0 competencies who are assigned to NAVAIR and Fleet Readiness Centers (FRCs).

WSTIAC personnel worked closely with their IISRP Teammates to select, analyze, fix and measure high-value aviation depot-level repairable (AVDLR) components that exhibit poor service life. The WSTIAC/IISRP team focuses on two metrics: component time on wing (TOW) and the component beyond capable maintenance (BCM) rate per thousand flight hours. (BCMs are items that require higher-level maintenance abilities that are not available at I-level facilities.)

The objective is to increase TOW, which will reduce component demand and/or reduce the number of components that are returned to the depot. Reduced component demand is the basis for the program's cost savings projections.

Components exhibiting high removal rates from aircraft are evaluated to determine if there are technical or maintenance-related causes for the poor operational service life. The team collaborates closely with cognizant fleet support teams, production managers/artisans and fleet maintainers to eliminate the causes for degraded service life through process changes, redesign or logistic element improvements.

After implementing the improvements developed and agreed to by the component stakeholders, IISRP monitors subsequent component removal and BCM rates to verify that the anticipated positive impacts on service life and operational readiness occur and to ensure that expected cost reductions are achieved. Actual TOW and BCM rates are compared to projections once per quarter. A review is conducted on each component that does not perform within established confidence intervals to determine why improvement projections are not being met.

Tangible results

Through the 3rd quarter of Fiscal Year 2007, the team:

- Completed 319 component studies resulting in more than 1,600 actions that led to improved support and component TOW
- Realized more than $352M in AVDLR cost-avoidance since program inception
- Realized a payback ratio greater than 4-to-1 on funds invested in team operations
- Saved $72M in verified material and labor costs
- Avoided 13,000 fewer component returns to the depots for repair

To improve their ability to deliver these results on time and on budget, the team completed numerous initiatives to enhance root cause analysis, data analysis, technical reporting and results monitoring. The team:

- Collaborated with Cost Wise Readiness Integrated Improvement Program leaders to develop a standardized issue/resource prioritization methodology for use by all program offices as they establish Air System Support requirements
- Completed and fielded a web-based benefits reliability matrix (BRM) database system that greatly improved component and action item tracking while increasing standardization and accuracy
- Fielded a comprehensive reliability growth analysis software package to analyze in-service reliability trends on selected components developed in cooperation with a leading commercial reliability and maintainability (R&M) software vendor
- Completed a comprehensive rewrite of the IISRP process guidance documents that incorporated the changes brought about by new tools and techniques
- Completed process reviews with the Airframes Management and Propulsion Management Boards to evaluate and compare the tools used by each IPT to manage, analyze and report programmatic metrics and cost information

Through their efforts, the WSTIAC/IISRP Team continue delivering improved readiness and lowered operating costs to the Fleet. These efforts have been recognized by NAVAIR leadership which awarded the team the Runner-up for the NAVAIR Commander's Award for 2006.

in the news...

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Stealthy Antennas

Minimizing the Radar Cross Section of an Essential Communication System Component

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Glaser Associates
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INTRODUCTION

The radar cross section (RCS) of a conventional antenna can be very large making it an easy target to pick up on basic radar systems. If the antenna is placed on a stealthy aircraft, for instance, it will destroy the aircraft's invisibility to radar rendering its stealth systems worthless. The radar system scanning the area of the aircraft would pick up reflections from each part of the antenna (or other components). The sum of the reflections arriving in phase results in the identification of a large RCS on the radar display. This sum can be as large as 35 decibels above a square meter (dBsM) including components from the radome which covers the antenna. The contribution from the antenna must be reduced significantly compared to each RCS contributed by all other aircraft components, such as the engine inlets, port canard, starboard canard, sweep leading edge, leading edge sweep, starboard wing tip, fuselage, port wing trailing edge, engine exhausts, and starboard wing trailing edge.

Stealthy antennas are designed to reduce the large RCS of conventional antennas. By replacing the large RCS of the conventional antenna with a much smaller RCS of a stealthy antenna, the aircraft is much more difficult to detect, and therefore, the cloak of invisibility will be maintained.

The need for stealth antennas has been highlighted by a joint document between the US and British defense establishments:

> *"Given the importance of antennas to the performance of distributed sensor systems, it is critical for the military to develop the fundamentals of electromagnetic propagation on or near the ground (< 10 cm) as a function of the operating frequency, bandwidth, ground cover such as soil, asphalt, cement, grass, bushes, trees weather, etc.... One needs to create design tools that can build and test high performance compact* ***stealth antennas*** *and antenna systems."*[1]

This paper reviews several stealth antennas that have been specially designed to have a minimum radar cross section, thus making them invisible to enemy radar. First, the four types of stealth antennas - plasma, absorber coated, shaped, and frequency selective surfaces are described. Then the division of the scattered fields between structural scattering and antenna mode scattering components is discussed. Next the tradeoff between radar cross section and antenna gain is evaluated. Finally, the measurement of antenna characteristics is discussed.

APPROACHES TO MAKING ANTENNAS STEALTHY

To reduce the radar cross section of an antenna, four methods can be used: shaping, radar absorbing materials, passive cancellation, and active cancellation. Of course, by introducing any of these methods, the performance of the antenna, such as antenna gain, is typically reduced.

Shaping

The strongest reflection of radar energy waves occurs when the incident waves are oriented at a normal (perpendicular) angle to the surface of the object. The shape of the antenna (or any surface) can be modified to direct the radar energy away from the antenna instead of reflecting it back to the originating radar system. This is done by tilting the face of the antenna away from the normal angle of incidence of the propagating radar energy waves. However, there will always be an orientation at which the surface is at a normal angle of incidence with the energy waves. The success of optimizing the antenna's shape, therefore, depends on making the stronger reflection angles occur at surfaces where the RCS is less significant than at others. Typically, a forward cone of angles is of primary interest for radar cross section reduction (RCSR), and hence the objective is to "shift" large cross sections out of the forward sector and toward the broadside. This can be accomplished by sweeping airfoils back at sharper angles.

Radar Absorbing Materials

As the name implies, radar absorbing materials (RAMs) reduce the amount of energy that is reflected back to the radar by absorption. Radar energy is absorbed through one of several loss mechanisms, which may involve the electromagnetic properties of the material. In general, the primary loss mechanism is the conversion of radio frequency energy into heat, although most radar absorbing materials do not get very warm when they are illuminated by radar energy.

The conductivity, dielectric, and magnetic properties of a material, which contribute to the loss mechanism, are lumped into a single effect of complex permittivity or complex permeability. Carbon and carbon-based materials have been used for more than 25 years including for applications such as the lining of anechoic chambers*. However, the chambers are usually too bulky and fragile for operational use on antenna applications. Magnetic materials are used for many operational systems including carbonyl iron which is much denser compared to carbon. Magnetic absorbers are heavy because of their iron content and are more narrowband than their dielectric counterparts. Basic RAM is often embedded in a matrix or binder such that the composite structure has specific electromagnetic characteristics for a given range of energy wave frequencies. Recently, an anechoic chamber has been lined with ferrite tiles, which have layers of dielectric and ferrite slabs. These layered composite materials cover the walls, ceiling and floor to attenuate radar energy.

Passive Cancellation

Passive cancellation is also known as impedance loading. The method, however, is very limited. The basic concept is to introduce an echo source whose amplitude and phase can be adjusted to cancel another source. This can be achieved for relatively simple objects, provided that a loading point can be identified on the body. Unfortunately, it is extremely difficult to generate the required frequency dependence for this built-in impedance. Furthermore, typical weapons platforms are hundreds of wavelengths in size and have dozens, if not hundreds of echo sources. Clearly, it is not practical to devise a passive cancellation treatment for each of these sources.

Active Cancellation

Active cancellation or active loading is even more ambitious than passive loading. In essence, the target must emit radiation with the wave characteristics needed to destructively interfere with the incoming pulse and cancel out any reflected energy. Such a system must be versatile enough to adjust and radiate a pulse of the proper amplitude and phase at the proper time. This implies that the target must sense the angle of arrival, intensity, frequency, and waveform of the incident wave. The target must also be smart enough to know its own echo characteristics for the particular wavelength and angle of arrival to generate the proper waveforms and frequency in order to successfully mask the object from the adversary's radar system.

SCATTERED FIELDS

This section discusses scattered electromagnetic fields that occur when an incident wave is scattered from a target. When an electromagnetic wave is incident on a target, electrical currents are induced in the target according to the continuum form of Ohms Law as presented in Equation 1.

$$J = (\sigma + j\omega\varepsilon)E \qquad \text{Equation 1}$$

where,

- J - Current density, amperes/m^2 (A/m^2)
- σ - Conductivity, mhos/m
- j - Imaginary unit
- ω - Angular frequency, radians/s
- ε - Permittivity, farads/m (F/m)
- E - Total electric field (incident + scattered), volts/m (V/m)

A scattered wave is produced by the secondary radiation of these currents. In the direction of the incident wave, the scattered field is reflected straight back to the source of the wave. This peak reflected wave is related to the standard antenna gain, G, and the radar cross section, as shown in Equation 2.

$$RCS = A \cdot G \qquad \text{Equation 2}$$

where

- A - peak effective area of the antenna, m^2
- G - peak gain of the antenna, dB

The peak effective area is a measure of the maximum area of the antenna. The antenna gain measures how narrow in angle the radiation beam is. For example, a half-wave dipole has a gain of approximately 2.1 dB and has a wide angular beam, while the gain of a conventional airborne antenna is much larger – approximately 35 dB, which has a fairly narrow angular beam.

The effective area is increased by the gain of the antenna. A high gain antenna should have a high radar cross section. To lower the RCS, the gain should be reduced. This is opposite to what antenna designers are supposed to do – increase the gain as much as possible.

The gain is related to the effective area as shown in Equation 3.

$$G = 4\pi A/\lambda^2 \qquad \text{Equation 3}$$

where

λ - wavelength

Combining the Eq. 2 and 3, the relationship shown in Equation 4 is obtained.

$$RCS = 4\pi A^2/\lambda^2 \qquad \text{Equation 4}$$

The antenna RCS can be divided into a structural component and an antenna mode component, as presented in Equation 5.

$$\sigma_{RCS} = \left|\sigma_s^{0.5} - (1-\Gamma)\sigma_r^{0.5}\, e^{j\varphi}\right|^2 \qquad \text{Equation 5}$$

where

- σ_s - structural RCS
- σ_r - antenna mode RCS
- Γ - magnitude of the complex reflection coefficient
- ϕ - phase of the complex reflection coefficient

Figure 1 shows that the RCS varies as the sine of the phase angle between the structural RCS and the antenna mode RCS from 0 to 360 degrees.

To establish a realistic concept of effective area, Table 1 provides the effective areas of several typical airborne targets (dBsM is the number of decibels of the airborne target below the RCS of a 1 m^2 area target).

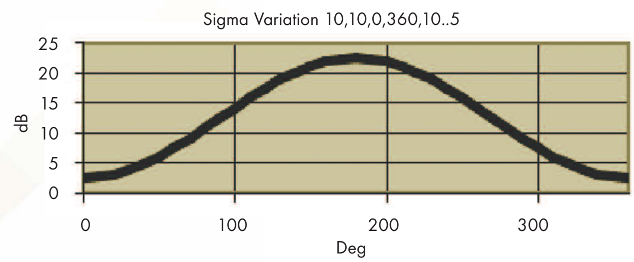

Figure 1. Variation of RCS (σ_{RCS}) with phase of reflection coefficient (ϕ, deg)

Table 1. Size of Typical Targets in dBsM [2]

Typical Targets	Effective Area (m^2)	dBsM
Classical bomber	1000	30
Classical fighter	100	20
	10	10
	1	0
	0.1	-10
Bird	0.01	-20
Insect	0.001	-30
	0.0001	-40

PLASMA ANTENNAS

A new antenna made of plasma (a gas heated to the point that the electrons are ripped free of atoms and molecules) works just like

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Figure 2. **Demonstration of a Plasma Antenna in the On-State. The Antenna Electrically disappears when De-energized.[3] (Reprinted with permission from [3]. ©2008 American Institute of Physics.)**

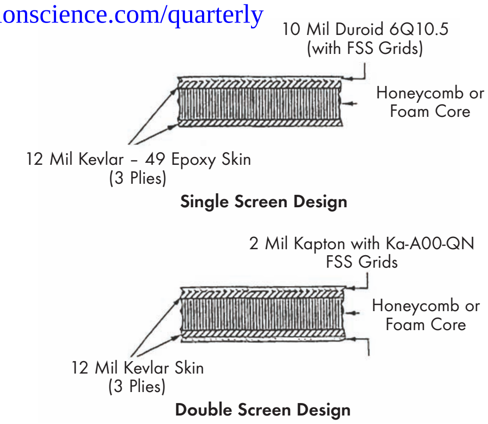

Figure 4. **Side View of a Four-Frequency DSL FSS Design Approach for the Cassini Project. [4] (©1994 IEEE, Reprinted with permission.)**

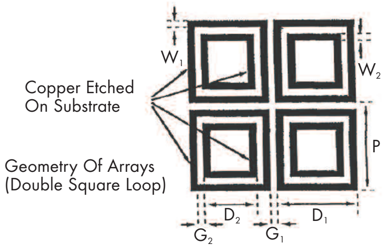

Figure 3. **Top View of a Four-Frequency DSL FSS Design Approach for the Cassini Project [4].† (©1994 IEEE, Reprinted with permission.)**

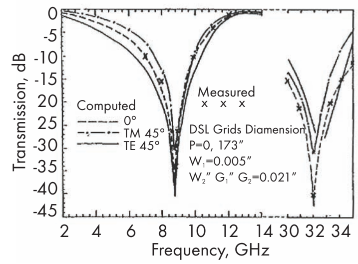

Figure 5. **Computed and Measured Transmission Characteristics of a Single Screen Four-Frequency DSL FSS with the Kevlar Honeycomb.[4] (©1994 IEEE, Reprinted with permission.)**

conventional metal antennas, except that it becomes invisible to radar when it is turned off. This concept is important for use on the battlefield and in other applications where antennas need to undetectable. In addition, unlike metal antennas, the electrical characteristics of a plasma antenna can be rapidly adjusted to counteract signal jamming attempts. Plasma antennas behave much like solid metal antennas because electrons flow freely in the hot gas, just as they do in metal conductors. But plasmas only exist when the gasses they're made of are very hot. The moment the energy source heating a plasma antenna is shut off, the plasma turns back into a conventional (non conductive) gas. In terms of radio signals and antenna detectors, the antenna effectively disappears when the plasma cools down. This prototype plasma antenna is stealthy, versatile, and jam-resistant. An example of a plasma antenna is shown in Figure 2.

BANDPASS RADOMES

Bandpass radomes can be used to restrict the bandwidth of the antenna, thereby limiting the signals that can penetrate and reach the antenna. A frequency selective surface (FSS) is part of the radome that protects the antenna. The characteristics of the FSS radome are that it is transparent at the operating frequency but rejects signals outside a band centered at the operating frequency. This feature allows the antenna to be low RCS for all frequencies outside this band of frequencies.

Frequency selective surfaces depend on regular geometric patterns cut into a conducting screen to produce a bandpass or a bandstop filter. These shapes could be rectangular or circular slots, annular slots, a single loaded slot, a four-legged symmetrically loaded slot, or a three legged loaded slot. A double square loop (DSL) design was used for four differing frequencies[4], as shown in Figures 3 and 4. Figure 5 shows that the computed and measured transmission of the single screen agree closely from 2 to 34 GHz.

A radome that protects the antenna from its environment (either in the nose of an aircraft or in a ground installation) can be employed as an FSS. The FSS radome must be transparent at operating frequency and it protects the antenna from the environment. Such a radome will influence the antenna pattern by refraction from the radome wall, loss from radome materials and multiple reflection, and increased sidelobes from multiple reflection. [5] The radome surface can be a conformal array of periodic elements that either reflects the incident energy within a frequency band (band stop) or transmits within a frequency band (band-pass). This is important because these filters make it harder for the enemy radar to see the stealthy antenna – an improved stealth feature. The boundary value problem for the radome can be solved numerically, resulting in the described behavior.

ANTENNA MEASUREMENT METHODS

This section discusses the techniques currently used to measure the properties and radiation characteristics of antennas. The key to these tests is the use of a network analyzer. Figure 6 shows the configuration for a typical near-field antenna measurement. Electromagnetic fields are measured by special probes that move at all points on a two-dimensional periodic lattice. A network analyzer records the field samples. The far-field is then computed using two dimensional Fourier transforms. The probe scans the plane in front of the antenna at on a regular X-Y grid.

The Data Acquisition Controller (DAC) is capable of cross-axis correction to improve overall scanner accuracy and planarity during the antenna measurement acquisition process. The laser system detects and corrects for small mechanical variations in the horizontal x-rails that will cause the vertical tower to tilt in both the z- and x-axis directions as it is moved along the x-axis. The correction system will dynamically compensate for tower deflection errors by adjusting the timing triggers to compensate for x-axis tilt and adjusting a z-translation stage during scanner motion. This technique ensures data is spatially accurate thereby reducing or eliminating the need to apply post acquisition software error correction. Rotation and z-translation stages for the probe are also part of the scanner.

Radio Frequency Subsystem

The radio frequency (RF) subsystem is based on a microwave receiver, RF source, local oscillator/intermediate frequency (LO/IF) source and LO/IF distribution unit. The system supports CW and pulsed antenna measurements from 0.8 to 50 GHz

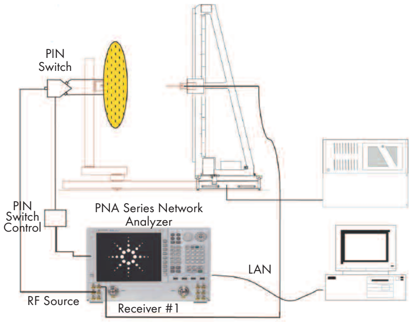

Figure 6. Typical Near-Field Antenna Measurement Configuration Using a Network Analyzer.[6] (© Agilent Technologies, Inc., 2008. Reproduced with permission, courtesy of Agilent Technologies, Inc.)

using frequency multipliers for operation above 26.5 GHz. The system is capable of multiplexing up to eight antenna under test (AUT) beams and two probe polarizations. The receiver provides accurate amplitude and phase measurements at a maximum rate of 2500 points per second. The sources can switch frequencies at a rate of approximately 8 msec. The AUT PIN (semiconductor diode p-layer, intrinsic-layer, n-layer) switch and the probe PIN switch have switching speeds of approximately 1 μsec.[6]

RF subsystem setup, timing and control are performed by the software running on the acquisition computer. The software also controls the scanner, and performs all data processing functions. The RF subsystem is fully reciprocal and supports both transmit and receive from the AUT.

RCS Measurement

RCS can also be measured using the network analyzer in the configuration shown in Figure 7. The far-field criterion is followed so that

$$R > 2D/\lambda^2$$

where

D - largest dimension of object

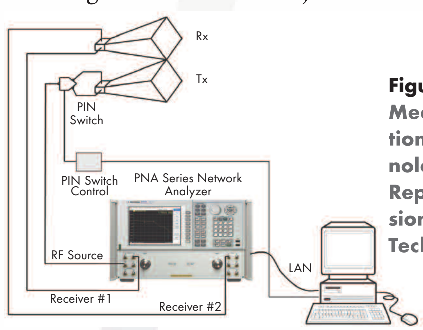

Figure 7. Typical RCS Measurement Configuration[6]. (© Agilent Technologies, Inc., 2008. Reproduced with permission, courtesy of Agilent Technologies, Inc.)

The primary concerns for the measurement instrumentation are sensitivity, frequency agility, and data acquisition times. Certain receivers can provide fast frequency sweeps with good sensitivity. The harmonic sampling down-conversion technology utilized in these receivers provided the fast sweep frequency agility desired for RCS applications, but had a tradeoff of not as much sensitivity as a fundamental or low-harmonic external mixing down-conversion technology. One system, which utilized external mixers, had the advantage of the superior sensitivity that was desired for RCS measurement applications, but had a tradeoff of requiring a relatively slower STEP frequency. The probe scans the plane in front of the antenna at on a regular x-y grid. The same RF subsystem used for antenna measurement is also used for RCS measurement.

SUMMARY

Stealthy antennas are necessary to hide the presence of a stealth aircraft as opposed to a conventional antenna which would readily reveal the stealth aircraft to an enemy radar system. The basic ideas involved in reducing the RCS of antennas include shaping, radar absorbing materials, passive and active cancellation. In addition, plasma antennas disappear whenever the transmitter turns off. A bandpass radome design minimizes the RCS of the aircraft. Measurement techniques for antennas and for RCS were also described in this article. In the future, it is expected that the design battle between a more stealthy antenna and a countermeasure of a more sensitive enemy radar will continue. This is analogous to the battle between the projectile with enhanced penetration capabilities and the improved armor technology that counters the projectile. The process continues!

NOTES & REFERENCES

* An anechoic chamber is a compartment designed to attenuate energy waves.

† Launched by NASA in 1997 the Cassini orbiter entered orbit around Saturn in 2004. Among many other studies, the orbiter used radio waves to measure the size distribution of particles in Saturn's rings.

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Dr. Jerome I. Glaser founded Glaser Associates as a consulting firm in antennas, microwaves, radar, and millimeter waves. He received a BS, MS, and PhD, all in electrical engineering from MIT. He has published 35 refereed papers, two book chapters, and holds seven patents and eight disclosures. Dr. Glaser is a Life Senior Member of the Institute of Electrical and Electronics Engineers (IEEE). Clients of Glaser Associates include Printronix, Schultz works, Edelweiss, Zigzag Electronics, Tomcat-Aerospace, Nextel Lightning, Balkan, iniquity Digital, and Netcom. Dr. Glaser was an Assistant Professor at MIT in the Department of Electrical Engineering and a Professor of Electrical Engineering Technology at DeVry Institute. He has also given short courses on "Low Observable Radar" in London, "Radar Cross Section" at Pt Mugu and Goodrich, "Electromagnetic Simulators" at UCLA Extension, and "Airborne Antennas" at Technology Service Corp. and Lockheed Aeronautical Systems.

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